CHAPTER 6

FLEXIBLE PAVEMENT DESIGN

6-1. Design Requirements.

Flexible pavement designs will provide the following:

a. Adequate thickness above the subgrade and above each layer together with adequate quality of the select material, subbase, and base courses to prevent detrimental shear deformation under traffic and, when frost conditions are a factor, to control or reduce to acceptable limits effects of frost heave or permafrost degradation.

b. Sufficient compaction of the subgrade and of each layer to prevent objectionable settlement under traffic.

c. Adequate drainage of base course to provide for drainage of base course during spring thaw.

d. A stable, weather-resistant, wear-resistant, waterproof, nonslippery pavement.

6-2. Determination of Pavement Thickness.

a. Bituminous concrete. When the computed thickness of the bituminous concrete is a fractional value, it will be rounded to the nearest full or half inch thickness. Values falling midway between the full and half inch values will be rounded upward.

b. Conventional flexible pavements.

(1) *General.* Conventional flexible pavements for roads, streets, and open storage areas consist of relatively thick aggregate layers with a thin (3- to 5-inch) wearing course of bituminous concrete. In this type of pavement, the bituminous concrete layer is a minor structural element of the pavement, and thus, the temperature effects on the stiffness properties of the bituminous concrete may be neglected. Also, it must be assumed that if the minimum thickness of bituminous concrete is used as specified in TM 5-822-5/AFM 88-7, Chap. 3, then fatigue cracking will not be considered. Thus, for a conventional pavement, the design problem is one of determining the thickness of pavement required to protect the subgrade from shear deformation. The steps for determining the required thickness for nonfrost areas are:

(a) Since summer temperature condition is considered most severe for subgrade shear failure, i.e., largest subgrade vertical strain under load, a modulus value of 200,000 psi (considered to be small for bituminous concrete) is used for the bituminous concrete.

(b) The traffic data determine the design loadings and coverages.

(c) An initial pavement section is determined using the minimum thickness requirements from TM 5-822-5/AFM 88-7, Chap. 3 or by estimation. The resilient modulus of the base and of the subbase is determined from figure B-1 and the initial thickness.

(d) The vertical strain at the top of the subgrade is computed using JULEA for each axle load being considered in the design.

(e) The number of allowable coverages for each computed strain is determined from the subgrade strain criteria using equation 5-5.

(f) The value of n/N is computed for each axle load and summed to obtain the cumulative damage.

(g) The initial thicknesses are adjusted to make the value of the cumulative damage approach 1. This may be accomplished by first making the computations for three or four thicknesses and developing a plot of thickness versus damage. From this plot the thickness that gives a damage of 1 may be selected.

(2) *Frost conditions.* Where frost conditions exist and the design thickness is less than the thickness required for complete frost protection, the design must be based on weakened subgrade condition. In some cases, it may be possible to replace part of the subgrade with material not affected by cycles of freeze-thaw but which will not meet the specifications for a base or subbase. In this case, the material must be treated as a subgrade and characterized by the procedures given for subgrade characterization. For information on designing for frost conditions, see TM 5-822-5/AFM 88-7, Chap. 3.

c. All-bituminous concrete pavements. The all-bituminous concrete pavement differs from the conventional flexible pavement in that the bituminous concrete is sufficiently thick (greater than 5 inches) to contribute significantly to the strength of the pavement. In this case, the variation in the stiffness of the bituminous concrete caused by yearly climatic variations must be taken into account by dividing the traffic into increments during which variation of the resilient modulus of the bituminous concrete is at a minimum. One procedure is to determine the resilient modulus of the bituminous concrete for each month, then group the months when the bituminous concrete has a similar resilient moduli. Since the bituminous concrete is a major structural element, the failure of this element due to fatigue cracking must be checked.

d. Pavements with a chemically stabilized base course. For a pavement having a chemically stabilized base course and an aggregate subbase course, damage must be accumulated for subgrade strain and for horizontal tensile strain at the bottom of the asphalt surface layer. Normally in this type of pavement, the base course resilient modulus is sufficiently high ($\geq$ 100,000 psi) to prevent fatigue cracking of the bituminous concrete surface course (where the bituminous concrete surface course has a thickness equal to or greater than the minimum required for the base course given in TM 5-825-2), and thus, this mode of failure is only a minor consideration. For most cases, a very conservative approach can be taken in checking for this mode of failure; i.e., all the traffic can be grouped into the most critical time period and the computed bituminous concrete strain compared with the allowable strain. If the conservative approach indicates that the surface course is unsatisfactory, then the damage should be accumulated for different traffic periods. For the pavement having a stabilized base or subbase, the stabilized layer is considered cracked for the purpose of design. The cracked stabilized base course is represented by a reduced resilient modulus value, which is determined from the relationship between resilient modulus and unconfined compressive strength shown in figure 4-3. When the cracked base concept is used, the subgrade criteria generally control the design. The section obtained should not differ greatly from the section obtained by use of the equivalency factors presented in TM 5-822-5/AFM 88-7, Chap. 3.

6-3. Design Example for a Conventional Flexible Pavement.
Design a conventional flexible pavement to support the following traffic:

Passenger car	2,000 operations per day
3-ax1e trucks	200 operations per day

As stated in TM 5-822-8/AFM 88-7, Chap. 3, this traffic results in a design index of 6 and the required pavement thickness is determined to be 22 inches for a subgrade CBR of 4.

a. Assume each axle of the passenger car carries 1,500 pounds and the front axle of the truck (single-axle, single wheel) carries 9,000 pounds and the rear axle of the truck (dual-axle, dual wheels) carries 32,000 pounds. The total number of operations and their corresponding coverages (n_i) for each axle load are tabulated in table 6-1. The design using the layered elastic method is discussed in the following paragraph.

b. Three pavement thicknesses (16, 20, and 24 inches) are assumed for the design. The bituminous concrete surface and base layers are 4 and 6 inches, respectively. The subgrade strains are computed for each thickness under each axle load using the layered elastic method. The modulus values of the

base and subbase layers are determined from the chart in figure B-1 of appendix B. The strains calculated using JULEA are tabulated in table 6-1. Based on the strain values, the allowable coverages (N_i) are determined from figure 5-1. The corresponding damage for each thickness under each axle load is computed as n_i/N_i and is tabulated in the last column of table 6-1. The total damage for each thickness is the sum of the damage of each axle load. A plot of the damage against the thickness indicates that the required thickness is 22 inches for a damage of one, which is the same thickness derived using the design index method in TM 5-822-5/AFM 88-7, Chap. 3. The subbase is therefore 12.0 inches. Table 6-1 shows that the damage caused by the passenger cars is so small that their inclusion in the damage computation could actually be neglected.

6-4. Design Example for an All-Bituminous Concrete (ABC) Pavement.
Design an ABC pavement for the same condition shown in previous example. For computation of the fatigue damage and subgrade damage, monthly temperature variations are considered; the corresponding variations of bituminous concrete modulus are shown in tables 6-2 and 6-3, respectively. Three pavement thicknesses of 8, 10, and 12 inches are used for damage computation. Normally for ABC design the subgrade damage will be the controlling criteria and thus the thickness for satisfying the subgrade criteria is first determined. The design is carried out in the following steps:

a. Subgrade failure.

(1) The subgrade strains are computed for each thickness under each axle load for each month using JULEA computer program. The bituminous concrete moduli for each month are shown in the last column of table 6-3. Because the effect of passenger cars on damage computation was proven to be negligible in the previous example, damage computation for passenger cars was not done.

(2) The allowable coverages N_i for each pavement are computed from the failure criteria shown in figure 5-1.

(3) The damage increments for each month are computed. The strains, allowable coverages, and the cumulative damage for the 32-kip tandem-axle, dual-wheels loads are tabulated in table 6-4. Cumulative damage for the 9-kip load is negligible. It is seen that nearly all the subgrade damage in the flexible pavement is done during the warmer months, i.e., May, June, July, August, and September.

(4) Similar computations are made for 9-kip single-axle, single-wheel loads. A plot of the cumulative damage for both 32-kip and 9-kip loads and pavement thickness indicates that for a damage of one, the required ABC thickness is 10.05 inches. For design purpose 10-inches are used.

Table 6-1. Strain Values and Damage for Trial Thicknesses.

Axle	Axle Type	Axle Load lb	Operations	Operations per Coverage	Coverages n_i	Subgrade Vertical Strain* 10^{-3} in./in. Pavement Thicknesses, in.			Allowable Coverage N *† Pavement Thicknesses, in.			Damage $D_i = n_i/N_i$ Pavement Thicknesses		
						16†	20††	24‡	16	20	24	16	20	24
1	Single-axle Single wheel	1,500	36,500,000‡‡	9.59	3,806,040	-0.09	-0.06	-0.03	Too Large	--	--	0.0	0.0	0.0
2	Single-axle Single wheel	9,000	1,825,000§	6.29	290,143	-0.85	-0.37	-0.19	867,000	12,850,000	Too Large	0.33	0.02	0.0
10	Tandem-axle Dual wheels	32,000	1,825,000§	1.03	1,771,844	-0.77	-0.56	-0.32	100,000	860,200	30,000,000	17.72	2.06	0.06
											Total damage	18.05	2.08	0.06

+The computations are made with the following conditions:

a. Tire contact pressure - 70 psi.
b. The moduli and Poisson's ratios for the AC surface and the subgrade are 200,000 psi, 0.4, 6,000 psi, 0.4, respectively. The Poisson's ratio of base and subbase is 0.35.
c. The layers are assumed to be fully bonded to each other.
d. The moduli of the base and subbase layers are determined based on the subgrade modulus.

Base	6 in. E - 30,250 psi	6 in. E - 40,432 psi	6 in. E - 51,739 psi
Subbase	6 in. E - 12,000 psi	10 in. E - 18,175 psi E - 11,393 psi	E - 26,380 psi E - 19,173 psi E - 11,013 psi

e. Interface conditions between each layer are fully bonded.

*From table 5-1.
**From figure 5-1 based on computed subgrade strain.
†The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 6 inches of subbase.
††The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 10 inches of subbase.
‡The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 14 inches of subbase.
‡‡36,500,000 - 2 axles x 2,000 operations per day x 365 days x 25 years.
§1,825,000 - 1 x 200 x 365 x 25.

Table 6-2. Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Bituminous Concrete Strain.

Month	Average[†] Daily Mean Air Temperature degrees F.	Design[††] Pavement Temperature degrees F.	Dynamic[†††] Modulus $|E*|$ 10^3 psi
Jan	47.5	54	1,600
Feb	50.7	57	1,400
Mar	58.0	64	1,060
Apr	66.1	72	700
May	73.3	80	460
Jun	80.5	88	280
Jul	83.1	91	230
Aug	82.7	91	230
Sep	77.3	85	340
Oct	67.2	73	670
Nov	56.2	61	1,200
Dec	49.3	56	1,500

[†]For fatigue damage of bituminous materials, the design air
 temperature is the average daily mean temperature.
[††]Obtained from figure 4-1.
[†††]Obtained from laboratory tests or other sources.

b. Fatigue failure in the bituminous concrete. To check if the 10-inch thick ABC pavement would fail by fatigue cracking, the cumulative damage in the bituminous concrete layer is computed for each month. The monthly modulus values of the bituminous concrete used in computations are from table 6-2. The results of the analysis indicate that the fatigue damage factor, i.e., $\Sigma n_i/N_i$, is 0.36 which is considerably less than 1; thus a pavement thickness of 10-inches meets both the subgrade criteria and the asphalt fatigue criteria.

6-5. Design Details.
Typical details for the design and construction of shoulders, curbs, and gutters of flexible pavements for military roads and streets are contained in TM 5-822-5/AFM 88-7, Chap. 3.

Table 6-3. Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Subgrade Strain.

Month	Average Daily Mean Air Temperature degrees F.	Average Daily Maximum Air Temperature degrees F.	Design Air† Temperature degrees F.	Design Pavement Temperature degrees F.	Dynamic Modulus |E*| 10^3 psi
Jan	47.5	56.4	52	57	1,600
Feb	50.7	60.1	55	62	1,150
Mar	58.0	68.0	63	70	790
Apr	66.1	76.0	71	77	540
May	73.3	83.2	78	86	320
Jun	80.5	90.4	85	95	180
Jul	83.1	92.9	88	97	160
Aug	82.1	92.8	88	97	160
Sep	77.3	87.4	82	91	230
Oct	67.2	78.1	73	82	400
Nov	56.2	66.4	61	69	830
Dec	49.3	58.3	54	61	1,200

†With respect to subgrade strain, the design air temperature is
  the average of the average daily mean temperature and the average
  daily maximum temperature.

Table 6-4. Strain Values and Damage for ABC Pavement, 32-kip Tandem-Axle, Dual-Wheels.

Month	Bituminous Modulus 10^3 psi	Subgrade Vertical Strain* 10^{-3} in./in. ABC Thickness, in.			Allowable Coverage, N_i ABC Thickness, in.			Damage $D_i = n_i/N_i$** ABC Thickness, in.			Cumulative Damage ABC Thickness, in.		
		8	10	14	8	10	14	8	10	14	8	10	14
Jan	1,400	-0.26	-0.20	-0.13	0.2×10^9	0.1×10^{10}	0.3×10^{11}	0.0	0.0	0.0	0.0	0.0	0.0
Feb	1,150	-0.29	-0.22	-0.15	0.1×10^9	0.7×10^9	--	0.01	0.0	0.0	0.01	0.0	0.0
Mar	790	-0.35	-0.27	-0.18	0.3×10^9	0.2×10^9	--	0.01	0.0	0.0	0.02	0.0	0.0
Apr	540	-0.43	-0.33	-0.22	0.6×10^7	0.4×10^9	0.7×10^9	0.03	0.0	0.0	0.05	0.0	0.0
May	320	-0.57	-0.43	-0.29	0.9×10^8	0.6×10^7	0.1×10^9	0.17	0.02	0.0	0.22	0.02	0.0
Jun	180	-0.80	-0.59	-0.39	0.8×10^5	0.7×10^6	0.1×10^9	1.89	0.22	0.01	2.11	0.24	0.01
Jul	160	-0.86	-0.63	-0.42	0.5×10^5	0.4×10^6	0.8×10^7	3.16	0.35	0.02	5.27	0.59	0.03
Aug	160	-0.86	-0.63	-0.42	0.5×10^5	0.4×10^6	0.8×10^7	3.16	0.35	0.02	8.43	0.94	0.05
Sep	230	-0.70	-0.52	-0.34	0.2×10^6	0.2×10^7	0.3×10^8	0.74	0.09	0.00	9.17	1.03	0.05
Oct	400	-0.51	-0.38	-0.26	0.2×10^7	0.2×10^9	0.2×10^9	0.08	0.01	0.0	9.25	1.04	0.05
Nov	830	-0.34	-0.26	-0.18	0.34×10^9	0.22×10^9	--	--	0.0	0.0	9.25	1.04	0.05
Dec	1,200	-0.28	-0.22	-0.14	0.14×10^9	0.14×10^9	0.75×10^9	--	0.0	0.0	9.25	1.04	0.05

*The computations are made with the following conditions:

a. The Poisson's ratios of the AC and the subgrade are both 0.4.

b. The interface condition between the AC layer and the subgrade is assumed to be fully bonded, as the subgrade vertical strain is much greater in the case.

c. Tire contact pressure = 70 psi.

**n_i is the total coverages for the 25 year design life divided into 12-month periods = 1,771,845/12 = 147,654, where 1,771,845 is obtained from table 6-2.